

Deflection and Strains in Buried FRP Pipes Subjected to Various Installation Conditions

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ABSTRACT

The primary objective of this research was to define more precisely the performance of fiberglass-reinforced plastic (FRP) pipe in relation to load-induced strains and deflections. Effects due to soil density, pipe stiffness, soil type, and installation techniques are discussed. An electronic device that describes the deflected profile of the buried pipe was used in such a way that bending strains were determined from changes in radii at 1-degree increments around the circumference of the buried pipe. The bending strains as determined by this profilometer have been found to correlate well with bending strains determined by strain-gauge measurements. The strain and deflection responses to certain installation irregularities for pipes with various stiffnesses have been monitored and documented. An installation in which a select material is placed around the pipe for up to 70 percent of the outside diameter and native material is placed above that point has been investigated. Heights of cover should be limited for these installations. The effect of neglecting soil placement in the haunch areas of the pipe has been investigated and reported. Proper haunching has been found to be a very important influence on strain levels in buried flexible pipes. Techniques used in this study are applicable to pipe materials other than FRP. Also, specific results can be applied to other pipe materials with similar stiffnesses.

A study that has dealt with both experimental and analytical methods concerning buried flexible pipe performance has been in progress at Utah State University for the past 3 years; the following parameters have been considered:

1. Installation:
 - a. Haunch (uniform versus poor),
 - b. Pipe zone (one versus two materials),
2. Soil density,
3. Pipe stiffness,
4. Soil type,
5. Pipe diameter,
6. Trench width,
7. Sheeting,
8. Time, and
9. Scaling due to size of cell.

This paper deals with experimental techniques and results that are a segment of this study. Effects due to soil density, pipe stiffness, soil type, and installation techniques are discussed. Effects due to pipe diameter, trench width, sheeting, time, and scaling were studied but are not within the scope of this paper. A parallel study using finite-element analysis was carried out that is being reported in a companion paper in this Record and elsewhere (1). The primary objective of the research was, by simulating field conditions, to define more precisely the performance of fiberglass pipe in relation to load-induced strains and deflections. Although the results reported are for a specific type of flexible pipe, the techniques used are applicable to other pipe materials. Also, specific results can be applied to other pipe materials with similar stiffnesses.

Testing was carried out in two soil-load cells at Utah State University, referred to as the small test cell and the large test cell.

Results reported here are for 24-in.-diameter fiberglass pipes. Pipes with the following pipe stiffnesses ($E/\Delta Y$), as defined in ASTM D-2412, were tested: 10, 20, 40, 100, and 200 psi. Strain and deflection data were measured and recorded as a function of vertical soil pressure.

TEST FACILITIES

Small Test Cell

The small test cell (Figure 1) is used to test pipe sections 5 ft long. The test cell has an opening at one end that allows access into the pipe for making various measurements. Sixteen hydraulic cylinders are located on top of the test cell, four cylinders on each of four beams. These cylinders exert pressure vertically on a 4- by 5-ft bearing plate placed on top of the soil. A maximum pressure of 1,800 psi can be applied to the cylinders to produce a maximum load of approximately 16,000 lb/ft² on the top of the soil. This applied pressure attenuates down through the soil so that the actual vertical load at the top of the pipe is somewhat less. This attenuation has been measured and the soil cell has been calibrated to simulate an embankment condition (2).

Large Test Cell

The large test cell (Figure 2) is used to test pipe sections up to 20 ft long with diameters up to 5 ft. The large test cell also simulates an embankment but

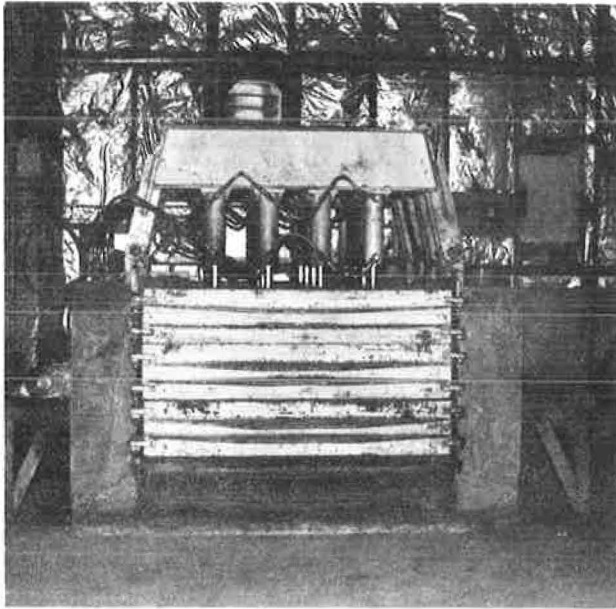


FIGURE 1 Small test cell.



FIGURE 2 Large test cell.

can be used to simulate trench conditions and other special installation conditions. This soil test cell employs 50 hydraulic cylinders, 5 on each of 10 beams. These cylinders apply pressure on a 10- by 20-ft bearing plate, which rests on top of the soil. A pressure of 30,000 lb/ft² can be applied.

Profile Device

A profile measuring device (profilometer) was used to record the inside profile of a pipe (Figure 3). The profilometer consists of a linear variable differential transformer (LVDT) mounted on an arm that is rotated around the inside of the pipe. This sweep arm is fixed to a spiderlike device by a bearing

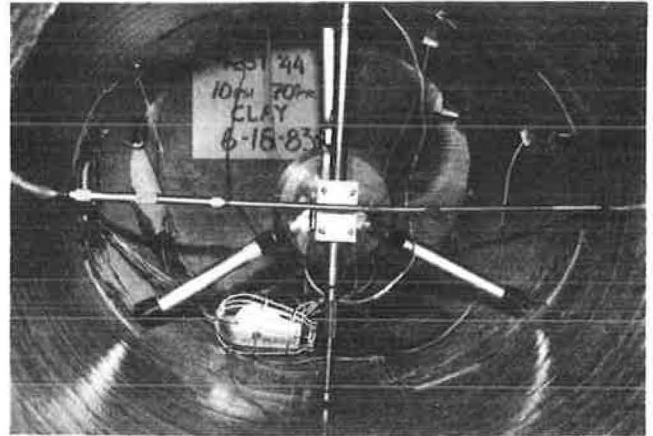


FIGURE 3 Profilometer and strain gauges used during testing.

that allows for the rotation. The spider has three spring-loaded adjustable legs that fasten the device to the inside of the pipe. The LVDT measures radial displacement of a roller mounted on the outer end of the sweep arm. The validity of the profilometer as a means of measuring changes in the pipe profile from which bending strains can be calculated was established by Knight (3).

METHODS

Three methods of taking data at incremented vertical soil pressures were utilized in this test program. Micrometer measurements for determining diameters were made. Profile data were recorded for every degree around the pipe and strain-gauge data were collected at 45-degree intervals both inside and outside the pipe.

Profile Data

The bending strain at any position on the wall of the pipe can be calculated if the original shape and the deflection of the shape of the pipe are known. The cross-sectional shape of the pipe is called the pipe profile. The profilometer (LVDT) precision is ± 0.0116 in. The profile of the pipe sometimes may look rough or jagged. This jagged nature of the profilometer data along with the small surface imperfections of the pipe presented several problems in calculating strains, for which the differences in pipe radii of curvature are used.

These differences are sometimes very small; therefore, extreme accuracy is needed. The profilometer data give a good representation of the actual pipe profile. However, the jagged nature can lead to an error in the calculation of the radius of curvature. This error was almost eliminated by smoothing the profile data with a cubic spline smoother. Also, instead of using three adjacent points 1 degree apart, three points 10 degrees apart were used for the calculation of the radius of curvature. This procedure proved to be successful because resulting bending strains agreed very well with bending strains measured with strain gauges. Figure 4 is typical of agreement of profilometer and strain-gauge data.

When the profile of the pipe was measured, the sweep arm of the profilometer was rotated 360 degrees around the pipe until it returned to its starting position. LVDT readings were taken at 1

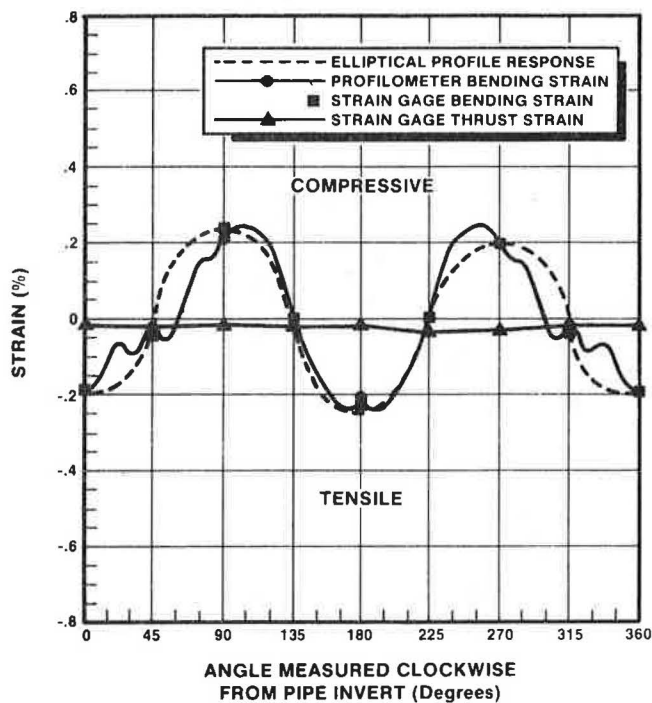


FIGURE 4 Strain versus position for theoretical elliptical response and typical uniform soil placement.

degree intervals around the pipe. The set of computer-converted LVDT readings for one complete sweep of the profilometer arm is referred to as a profile. At least four profiles were taken at each loading condition where the profile of the pipe was to be plotted. This set of profiles at a given load was later averaged by the computer program and the resulting profile was plotted as a profile of the pipe for that loading condition.

The prescribed test conditions were always symmetrical about the vertical diameter. Resulting data, on the other hand, were not always perfectly symmetrical, although differences were usually small. These differences could be traced to experimental error and primarily to the inability to place soil about the pipe in a perfectly symmetrical manner. Because the prescribed conditions were symmetric, bilateral symmetry about the vertical axis was forced by averaging data for a better representation of the prescribed conditions. This was accomplished by adding the radius of curvature of each point on the left-hand side of the pipe to the radius of curvature of its counterpart on the right-hand side of the pipe. The sums were then divided by 2 and these resulting radii of curvature were used in determining the profile and the strains for both sides of the pipe.

Strain-gauge data were not forced to be symmetric. The 180-degree position is at the top of the pipe, whereas the 0-degree and the 360-degree positions are the same point at the bottom of the pipe. It can be noted that the profilometer strain curve is symmetric about the 180-degree position, but the strain-gauge strains are not. If the strain-gauge bending strains at the 90- and 270-degree positions were averaged, they would agree quite closely with the profilometer bending strain at the same positions. This shows agreement between the profilometer and strain-gauge data (Figure 4).

Profile Plots

The pipe profile plots show the shape of the pipe after a soil load has been applied. From this shape, uncertainties in the strain and deflections are better observed. To view deformation trends qualitatively, a plot was made that gave the exaggerated difference between the undeflected pipe and the deflected pipe. The exaggerated profile is determined by multiplying the actual deformation by a factor of 4. Thus, the deformation shown in the exaggerated profile is 4 times the actual. See Figure 5 for a typical profile.

From exaggerated profiles, a relative magnitude and location of the compression and tension strains on the pipe can be better visualized. The exaggerated profiles are useful tools in helping to determine the relative magnitude of strains but should not be taken as a representation of the final shape of the pipe.

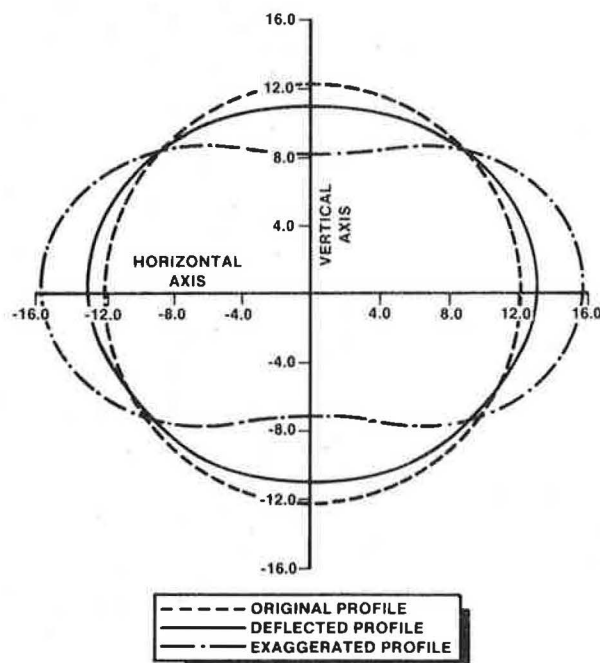


FIGURE 5 Deflected profiles as measured by the profilometer.

Load-Deflection Plots

For each of the tests, the vertical and horizontal deflections were measured at soil-loading increments. These deflections are plotted against the vertical soil pressure. For these load-deflection plots, the zero reference deflection is for the pipe installed in soil before any surcharge soil pressure is applied. Soil had already been placed at the prescribed density around the pipe and some deformation had already occurred because of soil placement. This initial ovalization was recorded but is not reported.

Strain Plots

Strain data were taken at various soil-pressure increments. Strain plots were made that contain the outside profilometer strain, which is the circumferential bending strain around the outside of the pipe as derived from the undeflected and deflected profiles. The undeflected profile (shape) is the

TABLE 1 Soil Data

Type of Soil	Percent Passing by Weight by Standard Sieve Size							Uniform Classification
	0.75 in.	No. 4	No. 10	No. 20	No. 40	No. 100	No. 200	
Clay				99.72	99.39	99.66	91.17	CL
Silty sand			98.75	97.04	92.77	53.66	40.47	SM
Washed sand		95.84	73.47	54.47	34.81	10.03	4.81	SW
Gravel	98.03	32.53	10.47	8.78	8.08	6.11	4.56	GW

free-standing pipe profile before soil placement. This strain was determined for each degree around the pipe and was plotted as a continuous curve. The outside bending strains were determined from profilometer data and strain gauges. The ring-thrust strains were determined by strain gauges at 45-degree intervals around the pipe.

Soils

The soils used in this test program are listed in Table 1. Complete data on these specific soils have been reported by Sharp (4).

Soil Placement

An effort was made to place the soil around the pipe in a uniform manner to the prescribed density. The exceptions to this were when the purpose of the particular test was to evaluate the effect of poor haunching. The haunch zones are those soil zones near the invert on either side of the pipe. Poor haunching is defined as placing soil loosely in the haunch zones with no effort to compact it to the prescribed density.

RESULTS

The following symbols or abbreviations are used in the figures to describe density, soil type, and haunch conditions: SS = silty sand, uniform = uniform placement, and P.H. = poor haunch. The leading number in the specification is the percentage of density. In the case of gravel it is the percentage of relative density. For other soils, it represents percentage of standard Proctor density. For example, "70 percent gravel uniform" stands for gravel at 70 percent relative density placed uniformly around the pipe. The specification "90 percent SS P.H." indicates silty sand at 90 percent Proctor density with poor haunching.

Influence of Different Degrees of Haunching Support

Figure 6 shows load-deflection curves for four separate soil-cell tests, all conducted with a pipe stiffness of 10 psi. Curve A represents a uniformly haunched gravel installation compacted to 70 percent relative density. Curve B represents the same soil type and pipe stiffness in which no care was taken to compact the gravel in the haunch area of the pipe. Curve C represents uniformly placed and haunched silty sand compacted to 90 percent standard Proctor, and curve D represents a 90 percent compaction silty sand in which no attention was placed on haunching. Comparison of the load-deflection curves for each of these tests shows that the influence of haunching is more severe for the silty sand than for the gravel. The gravel chosen for these tests flows

reasonably well, and the performance in the haunched and unhaunched cases is similar when the material is dumped in place. However, the silty sand must be compacted quite well with a mechanical compactor to obtain the 90 percent density. When the sand is uncompacted at the haunch, there is a larger difference in compaction than with dumped gravel. The shapes of the load-deflection curves are determined more by soil type and density than by haunching. Pipes poorly haunched in compacted silty sand deflect nearly twice as much as when careful attention is placed on attaining the proper density in the haunch area.

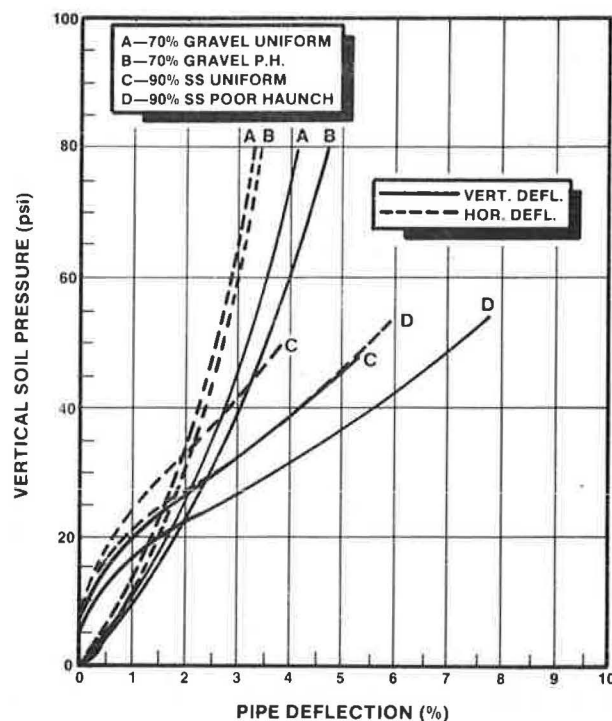


FIGURE 6 Load-deflection curves: uniform versus poor haunching ($F/\Delta Y = 10$ psi).

Figure 7 shows the strain-position curves for the tests indicated in Figure 6. In order to visualize the results in this type of a curve properly, it is desirable to keep in mind the strain response versus angular position for a pipe that is deflecting into an elliptical configuration. As can be seen from Figures 4 and 5, this elliptical configuration produces essentially a sine wave pattern in the bending strains; the peak strains are at the bottom, springlines, and crown of the pipe. This pattern can be contrasted with the strains from soil-box test installations as superimposed in Figure 7.

Note carefully the departure from the sine wave pattern for each of the curves representing gravel

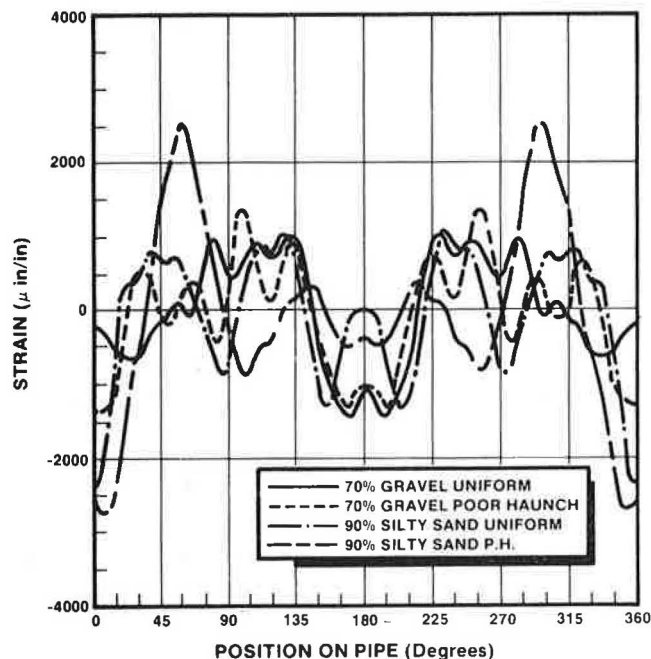


FIGURE 7 Strain versus position: uniform versus poor haunching ($F/\Delta Y = 10$ psi).

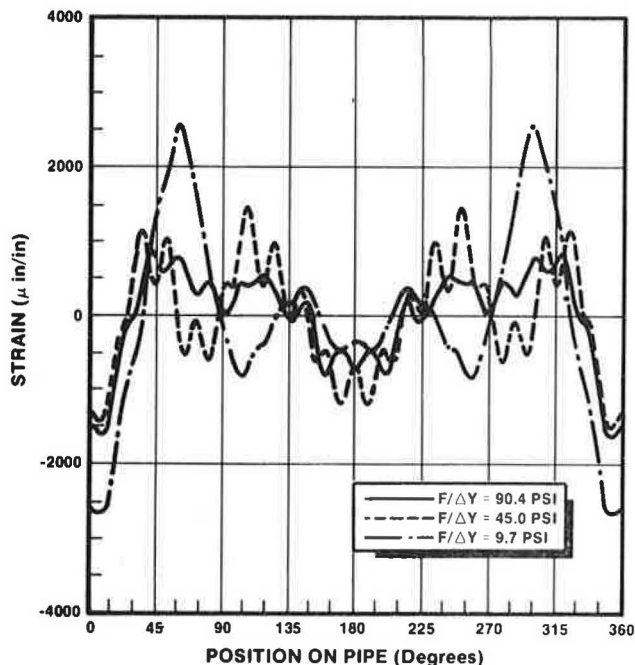


FIGURE 9 Strain versus position: stiffness response to poor haunching, 90 percent silty sand, poor haunch.

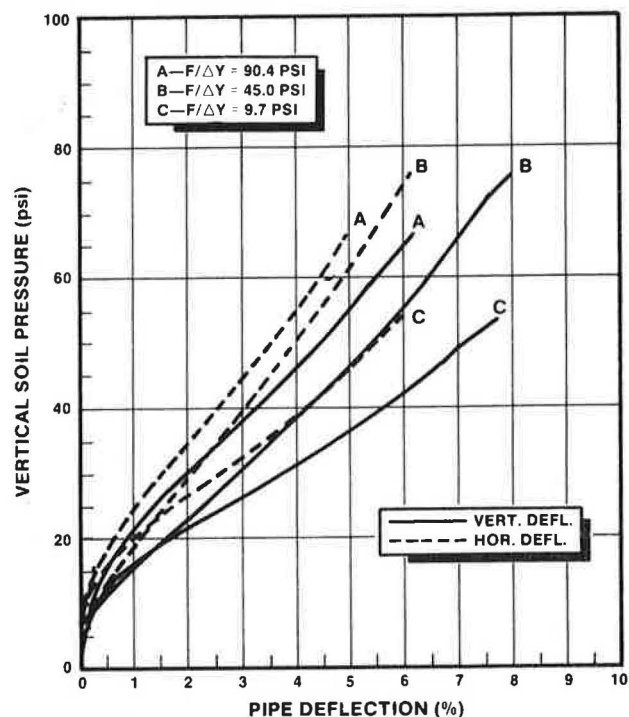


FIGURE 8 Load-deflection curves: stiffness response to poor haunching, 90 percent silty sand, poor haunch.

and sand beddings. When quality haunching has been neglected, as in curve D (Figure 6) in 90 percent silty sand embedment, the peak strains shift toward the haunch area of the pipe. There is a larger effect when haunching is neglected in the case of compacted silty sand than in the case of dumped gravel. It is difficult to make direct comparisons between each of the curves on a quantitative basis because the profiles represented result from slightly dif-

ferent soil pressure in each of the tests. Nevertheless, the trends in patterns of strain are important. Higher strains occur in the pipe when no attention has been given to haunching.

Pipe Stiffness Response to Poor Haunching

Figure 8 gives the load-deflection curve for three tests. The pipe for each of these tests was installed in 90 percent standard Proctor density silty sand with poor haunching. Curve A represents a pipe with a stiffness of 90.4 psi. Curve B represents 45-psi stiffness, and curve C, 9.7-psi stiffness. Because all other installation conditions are the same, this gives a picture of the influence of pipe stiffness when poor haunching conditions are encountered. The higher-stiffness pipe shows less deflection under the same load than does the lower-stiffness pipe.

Figure 9 gives the strain-position curves for the test shown in Figure 8. Increasing pipe stiffness tends to dampen out the strain peaks that appear in the haunching positions of the pipe as illustrated in curve C for the 9.7-psi stiffness pipe. The higher stiffness provides ability to bridge bedding irregularities such as poor haunching. Although the peak strain is higher for the 9.7-psi stiffness pipe at the loads represented, the strain level induced in the pipe is still relatively low for the 35-ft equivalent height of cover depicted.

Influence of Soil Density

Figure 10 shows three tests conducted in silty sand at densities of 90, 80, and 70 percent standard Proctor. The dramatic influence of soil density is readily apparent. The load-deflection curve for 90 percent density has characteristic initial steepness that levels out when loads approach 20 psi vertical soil pressure. The curves for 80 percent density have a short section of initial steepness and then

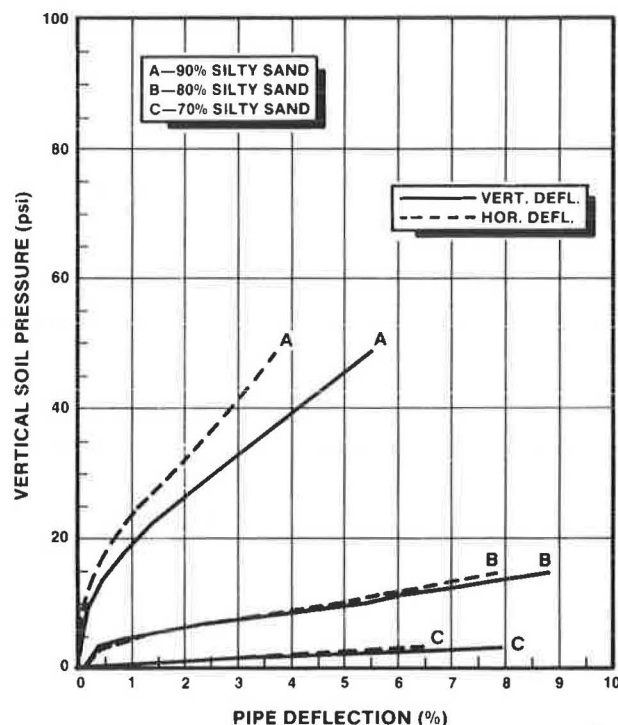


FIGURE 10 Load-deflection curves: influence of soil density, uniform compaction ($F/\Delta Y = 10$ psi).

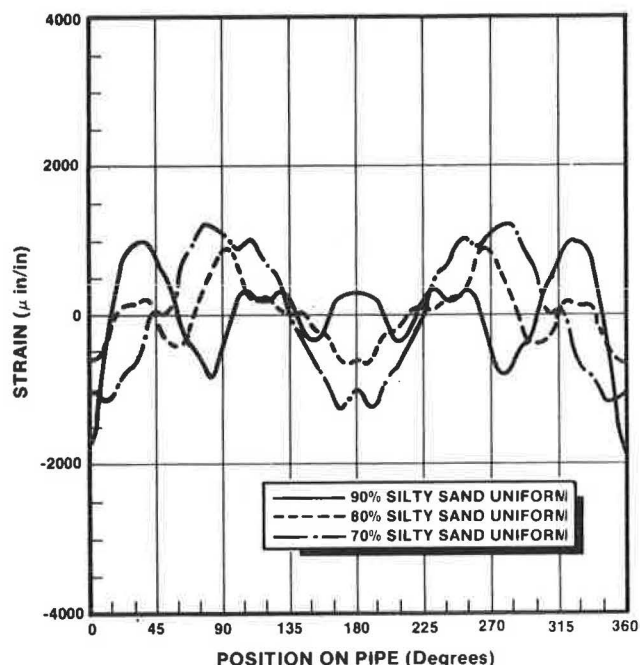


FIGURE 11 Strain versus position: influence of soil density, uniform compaction ($F/\Delta Y = 10$ psi).

another linear section of a much shallower slope than that for the case with 90 percent density. The 70 percent density was achieved simply by dumping the soil in place and an entirely different load-deflection curve results. Very large deflections under relatively small loads are indicated. The curve is almost linear throughout. The difference between

horizontal and vertical deflection is greater for the higher-density soils. This can be attributed to the horizontal restraining effect due to the higher compaction effort and the higher soil density.

Figure 11 shows strain versus position for each of the curves in Figure 10. Again, it is difficult to compare the magnitude of strain in each of these cases because of some differences in the vertical soil pressure at the time that each of the strain profiles was obtained. The case with 70 percent density in which the silty sand was simply dumped into place shows a pattern that most nearly represents the elliptical shape or sinusoidal pattern. As the density is increased, there is a tendency for the pipe to go into a higher mode of deformation in which a larger number of alternating positive and negative strain cycles is seen.

Influence of Soil Type

Figure 12 shows the effect of soil type on the load-deflection performance of pipes having a pipe stiffness of 10 psi. Each of the tests shown was conducted for beddings with uniform haunching. The least amount of deflection is shown in the washed sand at 90 percent compaction. For loads less than 30 psi vertical soil pressure, deflection was less in the case of silty sand at 90 percent Proctor density than for the case of dumped gravel at 70 percent relative density. The greatest deflections shown are for the compacted clay soil at 85 percent standard Proctor density. Loads in actual installations normally have a magnitude of less than 20 psi vertical soil pressure. The deflections for this load are less than 2 percent for all the soil types shown. A vertical soil pressure of 20 psi represents approximately a 25-ft height of cover.

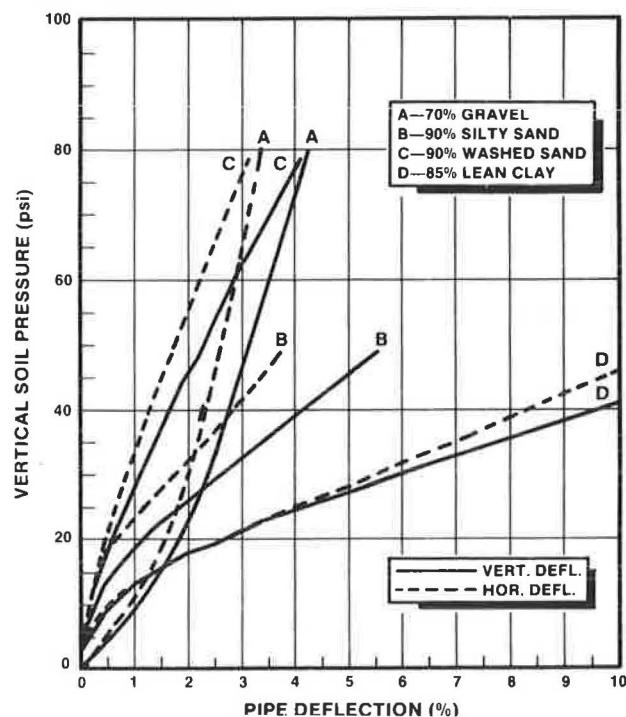


FIGURE 12 Load-deflection curves: influence of soil type, uniform compaction ($F/\Delta Y = 10$ psi).

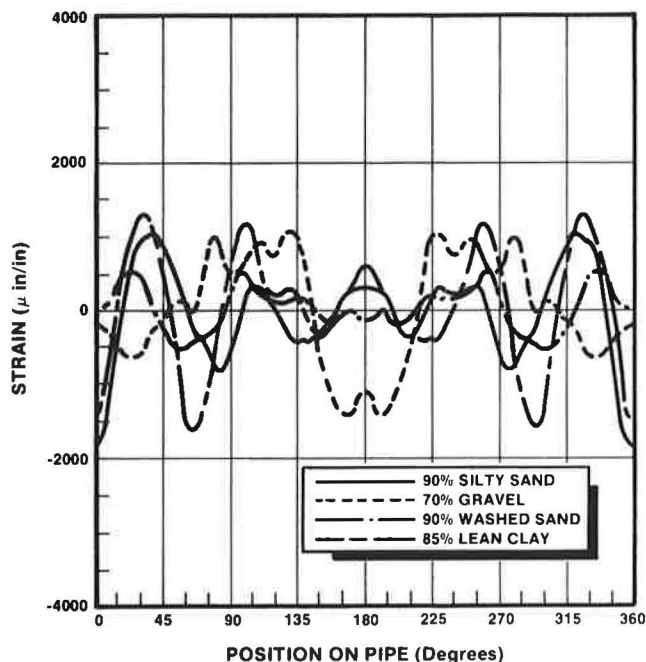


FIGURE 13 Strain versus position: influence of soil type, uniform compaction ($F/\Delta Y = 10$ psi).

Figure 13 shows strain versus position for each of the tests shown in Figure 12. For these cases, the strain pattern that most nearly represents the elliptical case is that of gravel bedding at 70 percent relative density, which represents the only case in which the backfill was dumped into place. The standard Proctor densities in each of the other cases were obtained by using an impact type of mechanical compactor, and deviations from the elliptical-shaped response are evident.

Influence of Installation Type

Figure 14 shows the load-deflection response for a gravel installation in which the gravel was placed throughout the pipe zone to at least the top of the pipe (curve D) and for split installations in which gravel was placed to 70 percent of the diameter of the pipe (curves A, B, and C). Two separate cases of this split-type installation are shown, one in which a silty sand was simply dumped on top of the gravel up to the top of the soil cell (curve B) and one in which the silty sand was placed at a density of 80 percent standard Proctor (curve C). Splitting the installation so that the gravel is taken only to a level of 0.7 times the diameter produces a drastic increase in the deflection (compare curves D and C). The load-deflection curve for the case of silty sand at 80 percent density on top of gravel appears similar to that for the case of silty sand at 80 percent density. A direct comparison of curves A and B shows the influence of pipe stiffness on performance in a split installation. The higher-stiffness pipe deflects less than the 10-psi stiffness pipe, as expected. However, compacting the silty sand placed on top of the gravel to 80 percent standard Proctor causes the 10-psi stiffness pipe to perform in a manner nearly equivalent to the 40-psi stiffness pipe under loads up to 10 psi surcharge load.

Figure 15 shows strain versus position curves for the tests shown in Figure 14. All three curves show peak strains occurring at the crown of the pipe and

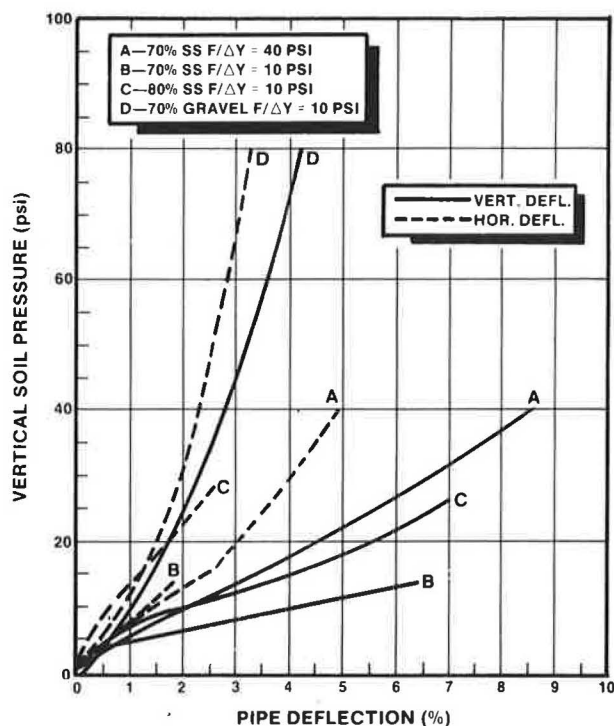


FIGURE 14 Load-deflection curves: influence of installation type, 70 percent gravel to 0.7 diameter uniform compaction.

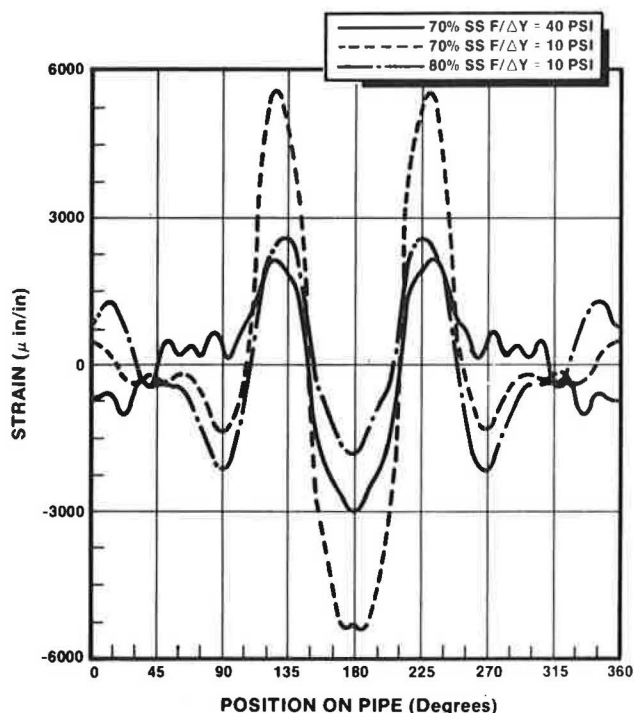


FIGURE 15 Strain versus position: influence of installation type, 70 percent gravel to 0.7 diameter uniform haunch.

adjacent to the crown in the pipe shoulder area. This is a significant deviation from the elliptical response. The peak strains are highest for the 10-psi pipe when the topsoil is only dumped in place. Peak strains are nearly equivalent for the 40- and 10-psi stiffness pipe when the 10-psi stiffness pipe

has been installed with silty sand at 80 percent density on top of the gravel rather than with dumped sand at 70 percent density.

RECOMMENDATIONS AND CONCLUSIONS

An electronic device (profilometer) has been developed that describes the deflected profile of a buried pipe in such a way that bending strains can be determined from changes in radii at 1-degree increments around the circumference of the buried pipe. The bending strains determined by this profilometer have been found to correlate well with bending strains determined by strain-gauge measurements. Strains determined by the profilometer are of particular value when peak strains occur at locations between strain-gauge placements. The ability to continuously describe the strain response of the buried pipe has provided some additional insights into the behavior of flexible pipes.

Techniques that simulate the effects of certain installation irregularities have been developed. The effects of differing degrees of haunching have been studied in particular. The strain and deflection responses to these irregularities for pipes with various stiffnesses have been monitored and documented.

In gravel installations where soil has been placed by dumping, a nearly elliptical pipe response is seen for all pipe stiffnesses tested. For these cases, wall strain is similar for the pipe of various stiffnesses.

In dumped or uncompacted sand, silty sand, or clay soils, elliptical pipe response is seen also. However, pipe stiffness plays a large role in deflection control, and lower strains occur in higher-stiffness pipe because of this lowered deflection.

In soils that are mechanically compacted to achieve higher densities, significant deviation from elliptical response can be seen in lower-stiffness pipe when it is poorly haunched. However, the better deflection control gained with these higher densities results in lower strain for the same load than when these soil types are dumped or poorly compacted. This is because strain is a function of deflection as well as shape. The reduction in deflec-

tion, which results from the higher soil density, more than offsets the strain induced by the more complex pipe shape.

When split installations are used that employ a high-modulus soil to a portion of the pipe diameter and a much lower-modulus soil to the top of the pipe, peak strains are shifted to the split transition area. This shift causes a deviation from the elliptical strain and deflection shape. Increasing pipe stiffness or increasing the modulus of the secondary bedding material reduces the peak strains. Height-of-cover limits should be imposed on split installations to control strains within desired limits.

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